

# Solid Wastes from Nuclear Power Production

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Radioactivity in nuclear power effluents is negligible compared to that in retained wastes to be disposed of as solids. Two basic waste categories are those for which shallow disposal is accepted and those for which more extreme isolation is desired. The latter includes "high level" wastes and others contaminated with radionuclides with the unusual combined properties of long radioactive half-life and high specific radiotoxicity. The favored method for extreme isolation is emplacement in a deep stable geologic formation. Necessary technologies for waste treatment and disposal are considered available. The present program to implement these technologies is discussed, including the waste management significance of current policy on spent nuclear fuel reprocessing. Recent difficulties with shallow disposal of waste are summarized.

## Introduction

The United States Department of Energy (USDOE) is concerned with the development and use of multiple energy sources to meet our needs in an occupationally and environmentally safe manner, and we believe the decisions involved in these energy matters cannot be made sensibly without an across-the-board look at potential hazards.

## The Nuclear Power Fuel Cycle

The generation of nuclear electric power involves a number of supporting or related activities at sites other than the nuclear reactor itself. These activities are generally called the nuclear fuel cycle. For the type of power reactor predominant in the United States today, the steps in the front end of the cycle are the mining and milling of uranium ore; enrichment in the uranium-235 content by the gaseous diffusion process, with chemical conversions before and after; and fabrication of the enriched uranium into fuel elements. Under normal reactor operating conditions, the fuel elements at time of removal still contain a significant inventory of unfissioned material, consisting of some of the original uranium-235 and some of the plutonium-239 which has been formed within the fuel by neutron capture in uranium-238.

Nuclear engineers and economists have frequently assumed that eventually partly spent nuclear fuel would be processed chemically to separate the residual fissionable material from the radioactive fission products, which are very much larger in quantity than would be required for any known or projected beneficial uses of them. The separated, purified fissionable materials would then be blended with fresh material in new fuel elements for reactor use, thus recovering some of the potential energy not extracted in the original reactor irradiation. The establishment of these activities is generally referred to as closing the fuel cycle. The entire cycle is shown in Figure 1.

Historically, nuclear weapons preceded nuclear power and the necessary materials have generally been produced and processed independently. However, in recent years, especially in the United States, there has been increasing concern that plutonium-239 could be diverted from a nuclear power fuel cycle into the development of nuclear weapons. In April 1977, a Presidential policy was announced containing two major parts: first, the United States would indefinitely defer the recycling of plutonium in the commercial nuclear fuel cycle; second, the United States would redirect fuel cycle research and development efforts toward new fuel cycles or toward new processing methods within the present cycle which would be more acceptable from an antiproliferation viewpoint. An example would be the blending of recovered uranium and plutonium at the spent fuel processing plant, so that

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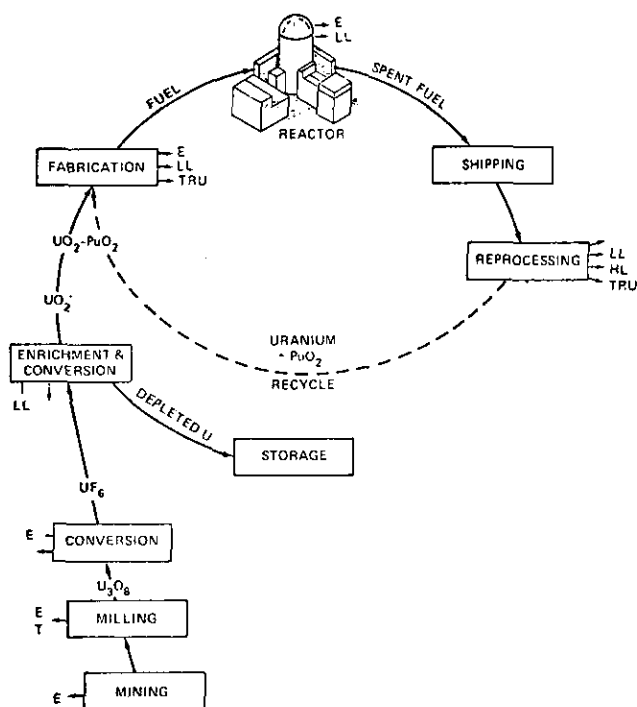


FIGURE 1. Commercial nuclear fuel cycle and types of waste generated: (E) releasable in effluents; (HL) high level rad waste; (LL) low level rad waste; (T) mill tailings; (TRU) transuranium contaminated rad waste.

diversion of plutonium from the next transportation step would be less attractive to the would-be weapons-maker. In the United States today, therefore, the closing of the back end of the fuel cycle is in what may be an extended "holding pattern," and the effects of this on the waste management program will be touched on later.

## Types of Nuclear Power Solid Waste

The first major point to be made about solid radioactive waste as a category is that it includes essentially all the radioactivity in all radioactive wastes, at least at times of final disposal. The first reason for this is that the technology for removing radioactivity from air and water effluents from nuclear power reactors and other large nuclear facilities is well developed. This technology is developed to such a point that radiation exposures at the proverbial fencepost due to the traces of activity released are quite small relative to the variations from state to state in natural background radiation. On a near-time basis, it is true that a good deal of

the retained radioactivity is in liquid wastes, especially at the spent fuel processing plant. It is also true that there are theoretically possible concepts for the permanent disposal of radioactive liquid waste. However, transportation safety restrictions on liquid radioactive materials would make intersite movement of liquid wastes economically prohibitive, so that their solidification is a practical requirement. Finally, from a final disposal standpoint, therefore, "solid radioactive wastes" and "radioactive wastes" become almost interchangeable terms.

On considering solid radioactive wastes from this permanent disposal standpoint, two broad categories are evident. One is solid waste for which there is a consensus of approval for disposal either by shallow burial, at locations carefully selected to minimize erosion and leaching, or by sea dumping at locations carefully selected to minimize effects of dispersion from the sea bottom. (Because the United States sea dumping regulations are so much more restrictive than those recommended by the International Atomic Energy Agency, the practice is effectively prohibited for United States prospective users and thus will not be discussed further in this presentation.) The other broad category is solid waste for which shallow burial or sea dumping is considered to provide insufficient isolation, or to require too much surveillance or too extended surveillance.

More isolated disposal has generally been proposed for high-level wastes (either in the form of discarded fuel, or the concentrated wastes that would be prepared from processing the fuel) and for other wastes contaminated with significant concentrations of the relatively small number of radionuclides which have the combined properties of long radioactive half-life and high radiotoxicity per unit weight. The primary natural example of this unusual combination is radium-226. Most of the man-made cases fall in the group known collectively as transuranium nuclides, the most highly publicized one being plutonium-239. The reasons for the presumed high specific radiotoxicity of these materials are unfavorable metabolic retention, and decay by  $\alpha$  particle emission rather than  $\beta$  particle emission.

The subcategory of radioactive wastes assumed to go to deep geological isolation needs to be broken down still further, for facility design purposes, because of differences in handling needs. High-level waste will need massive shielding and remote handling because of the penetrating radiation from the large quantities of fission products. There will also need to be provision for either active or passive cooling to remove the heat generated by the radioactive decay of these same fission products,

although the heat will probably not be enough to make the waste containers attractive for temporary use as heat sources. Bits of fuel element cladding (called hulls) will need highly remote handling because of penetrating radiation, but will probably not need heat removal. Various solid wastes from spent fuel processing plants (other than high-level) and from fuel fabrication plants (with plutonium recycle) may need semiremote handling, depending upon the degree of fission product contamination and the presence of plutonium nuclides higher than Pu-239. On a very long-term basis, all of the above are transuranium waste.

Figure 1 shows the subcategories of radioactive waste generated in the different steps of the nuclear fuel cycle. Table 1, derived from a generic environmental impact statement on commercial radioactive waste management now in preparation (1), shows volumes of some important types of waste relative to one year's operation of a typical large power reactor, and their radioactivity content. The concentration of activity in the relatively small volume of high-level waste is evident. The small volume of this high-level waste, relative to the value of the electrical energy, means that even if the disposal facilities appear to be quite expensive, the costs are still small compared to total nuclear fuel cycle costs.

## Availability of Technology for Waste Management

Probably the most comprehensive document on availability of technologies for radioactive waste management is ERDA 76-43. This report (2) was issued in May 1976 and has since been used as a basic resource for a generic environmental statement on the same subject. The key conclusions of ERDA 76-43 are as follows:

"... all technologies needed to manage radioactive wastes from the back end of the commercial LWR fuel

cycle are commercialized, available, or under development; there are no gaps. . . . Technologies for managing wastes from LWR reactors are fully commercialized. Technologies for treatment, interim storage, and transportation of wastes from fuel cycle operations such as fuel processing are commercialized, or ready for commercial-scale design and proof-testing, or can readily be implemented by adaptation of commercial practice for management of nonradioactive wastes. . . . The available technologies for final disposition of wastes are burial grounds and provisional storage in deep continental geologic formations. Stable geologies expected to be suitable for deep geologic isolation are known, technologies for site exploration and site selection are available, and design principles for waste repositories are known. Repository designs and qualification procedures will be specific to the site being considered; they can be developed as necessary when candidate sites are identified."

## Implementing Geologic Isolation Technology

Permanent disposal of high-level radioactive waste in geologic formations has been advocated for a number of years to preclude burdening future generations with close surveillance and periodic replacement of man-made storage systems, such as tanks or vaults. The general rationale for geologic disposal is as follows: if we find a formation which has been stable for geologically long periods of time; if no water is flowing through the formation; if we can excavate a cavity without harming the integrity of the formation; if we can place our potentially hazardous wastes within the cavity in chemical and physical forms which will not significantly react with the formation; and if we can then withdraw, carefully sealing all man-made openings, we should have reasonable assurance that our hazardous wastes will remain isolated from man's environment for geologically long periods of time into the future.

Over a number of years, the research and development effort of the old United States Atomic Energy Commission (USAEC) was directed toward

Table 1. Projected solid radioactive wastes based on one GW-year operation.

Type	Weight, MT (Tg)	Vol, m <sup>3</sup>	Activity, Ci (TBq)		
			Activation products	Fission products	Actinides
Reactor trash		600	$1.9 \times 10^6$ (7000)	$4.0 \times 10^5$ (148)	
Spent fuel <sup>a</sup>	38.2 (34.6)		$8.2 \times 10^6$ (300,000)	$1.3 \times 10^6$ (4,800,000)	$5.0 \times 10^6$ (185,000)
Reprocessing plant					
Transuranium trash		110	47 (2)	$7.9 \times 10^2$ (29)	$1.8 \times 10^4$ (670)
High-level		2.2		$5.3 \times 10^7$ (2,000,000)	$5.3 \times 10^5$ (20,000)
Hulls		12.3	$3.6 \times 10^5$ (13,000)	$2.7 \times 10^4$ (1,000)	$3.8 \times 10^4$ (1,400)
Non-TRU trash		50	1.7 (0.06)	8.4 (0.31)	
Fuel refabrication plant		11			$5.3 \times 10^5$ (196)
Decontamination and decommissioning		6		0.06 (0.002)	1.5 (0.056)

<sup>a</sup> If spent fuel is discarded as a waste, the reprocessing plant wastes and the fuel fabrication transuranium wastes will not exist.

the geologic isolation of prospective nuclear power fuel cycle high-level waste in bedded salt. In 1970, a specific closed-down salt mine at Lyons, Kansas, was tentatively selected, subject to the satisfactory completion of certain additional tests and studies. By mid-1972, it had become obvious that questions as to the integrity of this specific underground site might not be resolved favorably and soon enough. One of these questions involved locating and plugging nearby oil and gas exploration wells possibly dating back to the early 1900's; the other involved the nearby mining of salt by hydraulic methods with reported losses of large quantities of water underground. Dropping work on Lyons was a technical setback, and because the original tentative nature of the site selection had been largely ignored in the press, it was even more of a public acceptance setback. There were even news stories to the effect that we had been forced to remove radioactive waste from the mine, which was not so. The only radioactive materials ever placed in the Lyons mine were some irradiated fuel elements, which had been used to simulate solidified high-level waste canisters and completely removed at the end of an 18-month test period some years previously.

For several years after dropping work on Lyons, the AEC carried on a two-part program. One part was a search for one or more sites to replace Lyons, and the other part was to develop a repository at which commercial high-level waste could be stored in a readily retrievable manner pending the availability of a final disposal site. A main reason for this second part of the program was to be sure of meeting a commitment for the Federal Government to accept custody of high-level waste no later than ten years after its generation by the commercial spent fuel processor.

During the period of 1972 through 1974, considerable engineering effort was devoted to developing several design concepts for readily retrievable storage of high-level waste. However, a number of environmentally oriented groups, including the United States Environmental Protection Agency (USEPA), feared that AEC's interest in waste storage indicated an inability or lack of desire to go onward to permanent disposal. In January 1975, the operating functions of the AEC were transferred by act of Congress to a new agency, the United States Energy Research and Development Administration (USERDA), which then made a comprehensive review of waste management and other inherited programs.

As a result of this review, the proposed waste management budget submitted to Congress in January 1976 included a drastic increase in the geological disposal effort. In addition to having

large areas of land underlain by bedded salt or domed salt, the United States is also fortunate to have large areas of argillaceous rock (certain clays and shales). All three types of rock are considered by geologists to be potentially satisfactory for geologic disposal. The expanded program called for studies of available data, core drilling in promising areas, and possibly underground inspection of the best areas shown by the core drilling, all leading to identification of about six regional sites at which repositories could be constructed during the 1985-1995 period.

As stated previously, it now appears that U. S. spent nuclear fuel will be stored, possibly for an extended period, pending a final decision on whether to process it or discard it. Under this condition, the need for as many as six repositories over the next decade or so is not as clear as when the program was expanded. The need to demonstrate permanent disposal to environmentally oriented groups, however, is still urgent. Therefore, the present policy of DOE (which absorbed ERDA and certain other agencies on October 1, 1977) is to concentrate the geologic search for commercial waste repositories on salt, with a target of identifying two sites by late 1978 or early 1979 which could lead to 1985 repositories.

Continuing work in formations other than salt will be concentrated on the existing DOE reservations (former AEC sites) at Hanford and Nevada. These sites have underground formations of shale, granite, or basalt which could be suitable for permanent disposal of commercial waste; for permanent disposal of waste from the nuclear weapons program; or for extended retrievable storage of spent fuel. The evaluations of these reservations are to be accelerated so that judgment on their uses can be made in about two years.

One feature of our geologic disposal program which has not varied over the past few years is the concept of the test period. In this concept, at the beginning of repository operations the waste (either high-level or transuranium-contaminated) would be placed within the formation in some type of fitting or lining so that if necessary it could be readily retrieved without leaving contamination behind. This removal capability would be maintained during a test period, in which studies could be made with a significant inventory of actual waste in place. Probably the most important study would be to confirm the theoretical and laboratory work on the safe dissipation of radioactive decay heat. Only on successful completion of the test period would the retrievable mode be abandoned and the waste considered permanently emplaced. The test period concept is also under consideration for the high-level

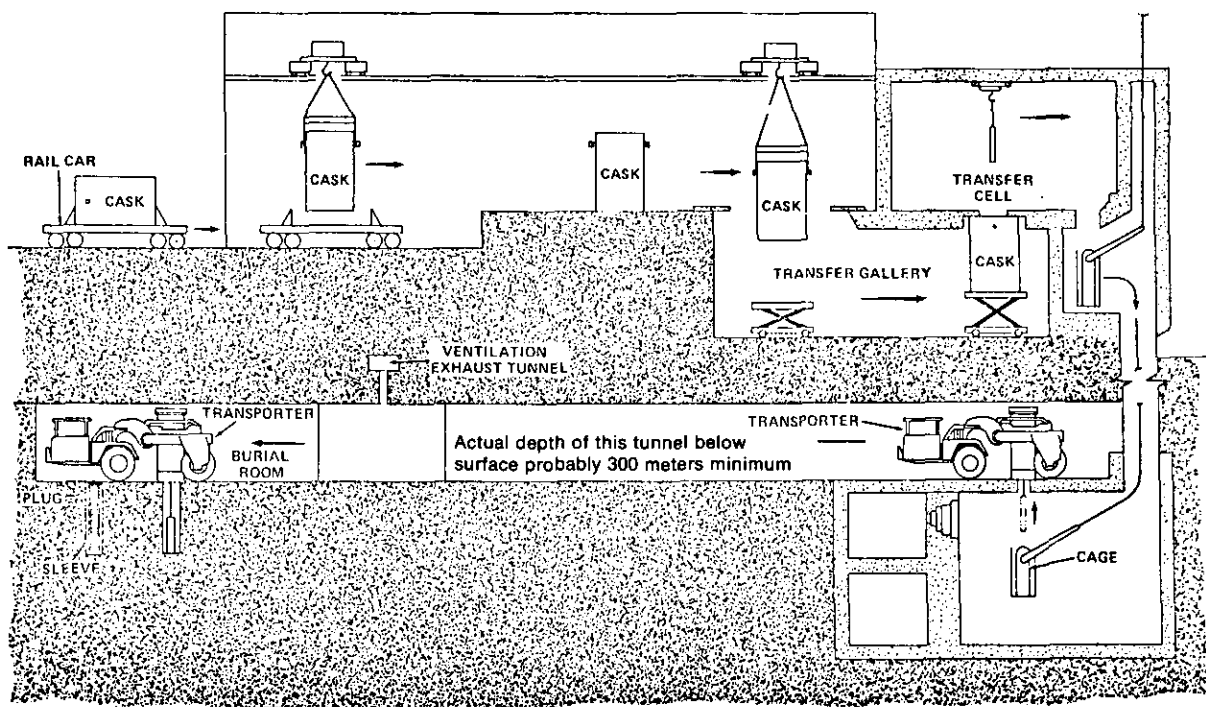


FIGURE 2. Schematic of permanent disposal repository operations; test phase, high-level section.

waste program in the Federal Republic of Germany (FRG), which has done a great deal of work in salt. The FRG and the United States are in close cooperation in the two programs.

Figure 2 (which is greatly compressed vertically) shows schematically how the high-level waste portion of a geologic disposal repository would operate during the test period. If necessary, the material would be removed by reversing the emplacement procedure. Fuel cladding, or "hulls" would probably be handled similarly since they would need to be lowered into the floor to provide shielding. Because of the need to keep the tunnels clear for movement of the transporter, the transuranium-contaminated waste packages would have to be placed in separate rooms or tunnels. However, since most of them would not need to be shielded, they could be closely stacked as in a warehouse.

In addition to mentioning these broad plans and features of the geologic disposal program, some specific highlights of the past year should be mentioned.

Reconnaissance of interior Gulf Coast salt domes in the State of Louisiana was conducted by Louisiana State University, the United States Geological Survey (USGS) and other contractors and consultants by use of remote sensing techniques (satellite imagery), seismic and tectonic field surveys, aerial photogrammetric and gravity sur-

veys, groundwater studies, compilation of stratigraphic data from existing boreholes, etc. Based on this work, several domes have been selected for further study, and a Geologic Project Manager, Law Engineering Testing Company of Marietta, Georgia, has been selected to manage these activities.

Reconnaissance (paper studies) surveys of portions of the Salina Salt Basin underlying Michigan, Ohio, and New York have been completed. Stone and Webster has been selected as Geologic Project Manager to conduct the subsequent area studies.

Reconnaissance surveys of the Mississippi and Texas Interior salt domes and of the Permian bedded salt deposits in the Texas panhandle are in progress, the latter in collaboration with the Texas Bureau of Economic Geology.

We have begun accelerated work in investigating potential sites at the Nuclear Test Station in Nevada and Hanford Reservation in Washington. Hanford is underlain with deep strata of basalt which may be suitable for a repository. Several geologic test holes have been drilled and a vigorous program is planned in the coming year.

An extensive borehole plugging program is in progress. This includes a comprehensive cement technology program aimed at developing satisfactory plug materials (concrete) and criteria for long-term sealing. A program to perform an *in situ* demonstration of plug emplacement techniques and

to develop instrumentation for monitoring the effectiveness of the plug to function as a borehole seal has begun.

A cooperative program has been initiated with Sweden, designed to conduct *in situ* heater tests at the Stripa mine which will provide thermal property information necessary to evaluate the feasibility of crystalline rocks (granite) to function as the host formation for high heat generating nuclear wastes.

An important part of the deep geologic disposal program is the technology for the treatment of the waste prior to its emplacement. The first United States salt mine concept called for the high-level waste to be disposed of in liquid form; however, transportation safety restrictions on liquid radioactive materials would have made this quite impractical except for a processing plant directly above a salt formation. (The use of unlined man-made caverns in geologic formations for storage of flammable and hazardous fluids is common in the United States chemical and oil industries.)

Solidification research and development was, therefore, started early in the program. One technique, which produces a dry oxide powder (calcine) has been routinely used for about 12 years to solidify high-level liquid wastes at one of the Government sites. Other techniques producing ceramic or glass-like solid forms have been developed through the pilot plant or "hot cell" stage, and this work is continuing.

Some people have objected to calcine as a form for permanent disposal of high-level waste, preferring a more insoluble and monolithic form, such as borosilicate glass. However, our view is that physical and chemical form is primarily important relative to accidental dispersion of materials in the early years when the waste is in a retrievable mode, either for transportation or storage. Over the much longer period of time involved in permanent disposal, the geologic formation itself must be considered as the safety barrier. Figure 3 is an attempt to

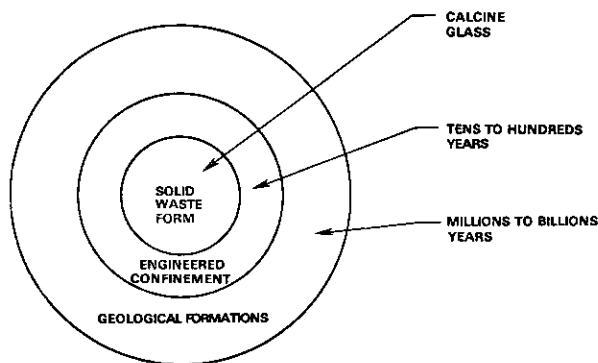


FIGURE 3. Barriers to the environment.

show this graphically.

Research and development is also continuing on treatment of transuranium-contaminated solid waste, focusing on incineration. This would have an economic advantage (volume reduction) and a safety advantage (preventing any subsequent accidental fires in combustible waste).

## Burial Grounds

The technology for shallow land burial of "low-level" radioactive wastes is relatively simple. The physical and chemical form of the waste is not relied on (except for the requirement that it be solid rather than liquid), with the soil itself being considered the safety barrier. At present, DOE has no operating or regulatory responsibilities for the shallow burial of commercial radioactive wastes, but is interested in them because of similarities to its own operations.

There are now six United States commercial solid radioactive waste burial grounds, all on land leased from state Governments, with the state responsible for surveillance after the burial ground is filled. This surveillance is financed by a small surcharge on the operator's burial fee. There is presently considerable interest in the significance of traces of radioactivity found in groundwater near two of these burial grounds. The position taken by the public health authorities in the two states involved (New York and Kentucky) in each case is that the levels of radioactivity which have been detected are not of any public health significance, but that the situation should be watched.

In both of these cases, the problem seems to have come from mismanagement of surface waters (rain or snow-melt), which were allowed to collect in open waste trenches and then pumped out. This is much easier to correct than an error in predictions about subsurface waters coming into contact with the wastes after completion of burial.

Over the past several years, a number of studies have been made on the Government burial grounds, or are continuing, involving reevaluation of the original site selection; engineering methods for correction of undesirable conditions that might be detected; or criteria for site selection for possible new burial grounds. The results of these studies are being made available to commercial burial grounds' operators and regulators as soon as they are finished.

## Uranium Mill Tailings

Of all types of solid radioactive waste, the largest by volume is the uranium mill tailings piles. United States uranium-bearing ores are generally low grade

(in the range of 0.15% to 0.25% uranium by weight) so that the milling residues are almost the weight of the original ore removed from the mine, and because of the crushing and grinding process are actually bulkier. The residues (tailings) also contain almost all of the daughter products of uranium decay, of which radium-226 and its gaseous decay product, radon-222, are the most publicized.

Experience at the uranium mill has shown that tailings piles are not an environmental problem if they are kept wet to prevent wind erosion and properly diked to prevent water run-off. Radon, even from large piles, is not noticeable above background beyond ~ 0.8 km. (Radon is a noticeable component of worldwide natural radiation background due to traces of radium in virtually all kinds of rocks and soils.) However, if the tailings are used as construction fill beneath or around structures used for human occupancy, radon levels to which people are exposed within those structures can approach the levels found in a ventilated underground uranium mine. Such construction use of tailings was common in one U. S. community (Grand Junction, Colorado) from the early 1950's until 1966, but has been prohibited by Colorado regulations since then. For the past several years, removal of tailings from beneath some of the Grand Junction buildings has been done with Federal and state funding.

## Decontamination and Decommissioning

The decontamination and decommissioning of surplus nuclear power reactors and other large fuel cycle facilities has one special potential waste management aspect. This is not in the nature of the radioactivity, since it is unlikely that the spectrum of radionuclides in decommissioning wastes will be different (except for decay) than in the wastes during the operating years. It is also not a matter of waste volumes, although remote handling technology may need to be adapted to the breaking down of massive pieces of equipment into shippable-sized packages. However, if the decision is made to entomb the facility, we have a new radioactive waste site, and the criteria for other kinds of permanent waste disposal sites may not be fully applicable to passing judgment on this decision.

It is not presently clear what the long-term regulatory policy will be on the proliferation of en-

tombed nuclear facilities. If the eventual trend is against them, economics will probably dictate that a much higher priority be given at design time to features which will make the later clean-up and disassembly of the facility much easier than they are now.

## Conclusion and Summary

Despite a number of major changes in the direction of the national nuclear policy, the goal of early location and construction of geologic repositories for the permanent disposal of radioactive wastes remains unchanged. Such facilities, designed for the permanent isolation of vitrified wastes, should also be suitable for the retrievable storage of unprocessed fuel.

The present program will focus our activities in regions where repositories can be available in the mid-1980's, namely promising salt formations, and on existing reservations where location of repositories in land already dedicated to handling nuclear materials would be politically and technically preferred. We will concentrate on identifying real technical alternatives for both geologic and surface storage facilities which could be selected from in about two years time for operation in the mid-1980's.

We currently enjoy strong Congressional backing as indicated by a growing budget to meet an expanding program. We intend, however, to improve our relationships with state and local Government officials to involve them in the decision-making process and to improve public acceptance for the siting of geologic facilities.

We are currently faced with large quantities of existing radioactive waste and we must face up to the issue and provide permanent disposal of these wastes with minimal requirements for future care and surveillance. The future use of nuclear power depends upon a successful implementation of this program, and the time to act is now.

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2. ERDA. Alternatives for managing wastes from reactors and post-fission operations in the LWR fuel cycle. Energy Research and Development Administration, ERDA 76-43, May 1976, Vol. 1, p. 5.